Advanced Road Data for Transportation and Traffic Engineering

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Abstract

Road engineering is heavily dependent upon good data and predictive modeling of traffic volumes and conditions. Recent rapid technology advances has made it possible to gather real time datasets at the detailed level based upon real time Vehicle Detection Stations and process vast quanta of vehicle by vehicle data. However, there are many challenges with building historical and real time systems that can effectively manage the data volumes and deliver advanced information that enhances road engineering planning and design. Main Roads Western Australia (MRWA) has taken up the challenge with the cutting edge Network Intelligence Project and a key outcome already achieved is the development of an innovative "Data Cube". As a result, MRWA has developed capability to report upon the newly formed National Performance Indicators (that are based upon the detailed real time traffic data collected throughout the year) for freeways through an automated system. MRWA can also report upon a wide range of traffic engineering, social, economic and environmental parameters (such as greenhouse gas emissions), through an estimation process that considers vehicle by vehicle parameters reported by the established Vehicle Detection Stations.

1. BACKGROUND

Main Roads Western Australia (MRWA) is the State road (transport) agency, with responsibility for some 17 800km of major roads, all traffic signals and all regulatory road marking and signage in Western Australia. The geographical distribution of MRWA's assets exceeds all the other road transport agencies and MRWA is considered to be one of the key stakeholders in Intelligent Transport Systems (ITS).

MRWA developed its ITS strategy for 2005 and 2010 with a key objective being:

> 'By 2010 Main Roads will be recognized as a leading Australian road agency in achieving the benefits of Intelligent Transport Systems'[1].

The Strategy points to the following ITS Objectives:

1. Timely and accurate information to road users and managers;
2. Effective control of road use;
3. Improved road safety, access and compliance;
4. ITS capability, resources and awareness of developments; and
5. Minimise risk to Government.

Advanced road data is relevant to the achievement of all Strategy objectives, resulting in the initiation of the *Network Intelligence Project* (NIP) and a Network Intelligence Technical Reference Group (NITRG) to oversee and contribute to the project.

The purpose of the NIP is to provide the data and information foundation for current and future ITS systems within an efficient and robust architecture that can be supported in the long term. This paper describes the NIP, documents major achievements to date and summarises future planning.

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[1] Intelligent Transport Systems Strategy 2005 – 2010, Main Roads Western Australia, December 2004.

2. MOTORWAY/FREEWAY VEHICLE DETECTION STATION DATA

Prior to the ITS Strategy, Main Roads had few Vehicle Detection Stations located on its freeway (motorway) network and the only source of operational information was through Closed Circuit Television (CCTV) imagery. By contrast, datasets did exist for the arterial road network through the Sydney Coordinated Adaptive Traffic Signal (SCATS) system. Accordingly, a program to install foundation Vehicle Detection Station (VDS) infrastructure along the freeway network was initiated.

These circumstances affected the priorities for the NIP as work was required to define the data set to be delivered and to establish systems to collect and manage the data.

2.1 The Raw Data

While many road authorities collect aggregated data from their motorways, generally ranging from 20 second (e.g. Victoria) to 2 minute aggregations, interview with practitioners revealed a view that this was principally to reduce computer processing and data storage requirements.

The few sites we already had in place were sending vehicle by vehicle records, including attributes such as:

- VDS Number;
- Record Number;
- Date and Time;
- Traffic Lane;
- Vehicle Direction;
- Vehicle Speed;
- Vehicle Length;
- Headway; and
- Gap.

Detailed assessment of the feasibility to retain the existing data format for the pending VDS sites was undertaken and it was found that data storage and processing costs had fallen sufficiently for this to be considered a suitable alternative. In addition, the NITRG agreed that aggregation of the data would limit future flexibility in operations, analysis and reporting. Accordingly, vehicle by vehicle data records were agreed and implemented for all VDS.

2.2 Data Cube – The Future of Historical Analysis

Investigation was commissioned to consider the data analysis needs of Main Roads and the most suitable methodology given the “Raw Data” decision noted above and emerging software technology solutions. It was found that ultimately a number of

application specific options would be required, however, for fast access to detailed data views to meet most of Main Roads requirements, a Data Cube would provide the best solution for the first project iteration.

A data cube has some similarity to a traditional data base that contains data aggregations such as 1 minute data averages / totals. The traditional data base contains two "dimensions" involving space (the location of VDS and traffic lanes) and time; by comparison, a data cube has more dimensions. Within each cell formed by the dimensions are the Measures, which is identical to the data within the cells of a traditional database.

The Main Roads Data Cube is allowing a wide range of analysis to be undertaken ranging from detailed views of network performance to National Performance Indicator reporting.

2.2.1 Main Roads' Data Cube Dimensions

The role of the Dimensions in a data cube is similar to a library catalogue; they structure the data to increase the efficiency at which data may be retrieved.

Main Roads' data cube presently has five dimensions:

1. Space;
2. Time;
3. Speed;
4. Vehicle Length; and
5. Traffic Density.

The Space dimension is very similar to a traditional database and contains aggregation options such as traffic lanes, freeway sections, freeway directions, freeway names and the freeway network.

The Time dimension is very similar to a traditional database and contains aggregation options such as minutes, peak period, working day, school holiday, day of week, day of month, quarter and annual.

The Speed dimension sorts data records into speed range place holders. This enables calculations and aggregations to be completed that are only associated with vehicles travelling within certain speed ranges. For example, the speed enforcement agency may wish to know where and when they should be focusing their speed enforcement

attention; analysis that is enabled by this dimension. A vehicle by vehicle database would also enable this analysis, however, this is not enabled with traditional aggregated freeway data.

The Vehicle Length dimension is fundamentally length based vehicle classification and like the speed dimension, it allows measures to be viewed for selected vehicle length categories. For example, a freight traffic restriction was imposed on a section of Leach Highway, seeking re-routing of more freight traffic onto an alternative route on Kwinana Freeway. The Vehicle Length dimension allows data for the restricted vehicles to be quickly considered and compared.

The Traffic Density dimension relates to the Highway Capacity Manual and Level of Service, which is fundamentally defined by density. It considers the number of vehicles experiencing different traffic densities based upon vehicle separation (headway) and vehicle speed.

With these dimensions in place, a data analysis / search can quickly focus upon the data cells that are relevant to the search criteria compared with requiring a search through all data within the specified time and space range. Further, the data cube pre-calculates key data aggregations, significantly reducing the time associated with data extraction.

2.2.2 Main Roads’ Data Cube Measures

Main Roads’ Data Cube currently contains 33 different measures, such as speed, volume, density, occupancy, estimated CO_2 emissions, ‘avoidable’ CO_2 emissions, etc. Each measure is calculated from the fundamental line of vehicle data as data is entered into the cube. For example, traffic density is calculated by traffic volume divided by vehicle speed. In addition, the “volume” for a single vehicle is based upon the inverse of the headway.

The measures are calculated for every vehicle record and then aggregated into the relevant cell of the Data Cube. For example, if a vehicle data line was processed and found to be travelling at 82.5km/h, experiencing traffic density of 26.2 veh/km, of length 18.2m at the location of VDS 10 and recorded at 9:01:30am 19 February 2009, then it’s measures would be recorded within the cube cell Speed: 82-83km/h, Level of Service D, Vehicle Class 2, Mitchell Freeway 0 - 0.5km and 9:01 – 9:02am 19 February 2009.

2.3 Advanced Data Sets and Detailed Historical Analysis

The Main Roads’ Data Cube allows a wide range of detailed data views, supporting detailed Traffic Engineering analysis of freeway performance and planning of future

projects and Intelligent Transport Systems. In addition to enabling traditional speed, volume, occupancy and density data views, the consideration of advanced information and datasets has been enabled and this is moving towards a sustainability framework.

Analysis undertaken for Kwinana Freeway considering the “direct costs” of congestion during the morning peak period and the Main Roads Data Cube enabled a cost profile (see Figure 1) and heat map (see Figure 2) to be prepared. The “direct costs” of congestion is a conservative calculation that is based upon the extra travel time, excessive travel reliability time allowances, fuel consumption and environmental emissions (e.g. CO_2, CO, NO_x, VOC and Particulates) that arises when vehicle speeds fall beneath 60km/h. The choice of 60km/h was based upon optimums for freeway productivity, fuel consumption and emissions coinciding with approximately 70km/h average freeway speed and the view that with freeway management, almost all vehicles should be travelling above 60km/h if laminar flow is maintained.

Similar plots can be prepared outlining the net costs of transport within these areas.

The model is including economic and environmental costs associated with transport, noting also that the travel time element does have social implications for commuters. Therefore, the analysis that has been enabled is heading in the direction of a Sustainability view of transport operations.

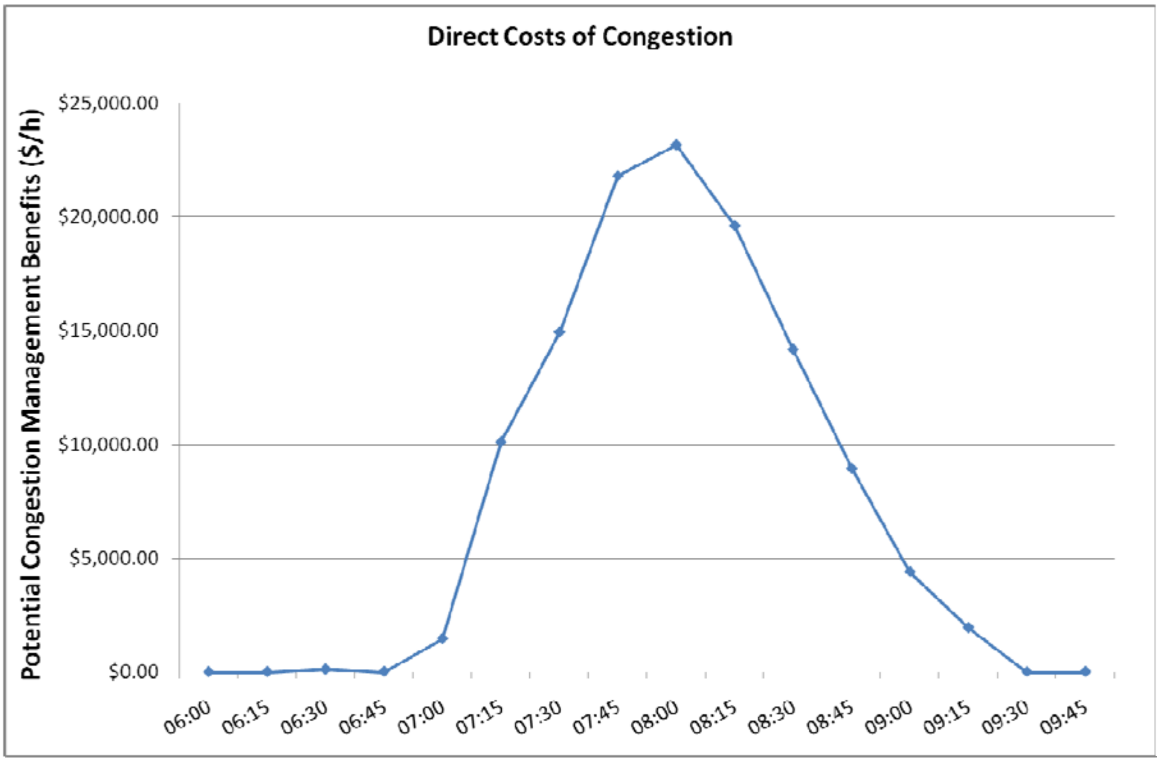

Figure 1: Direct costs of congestion Kwinana Freeway north bound, Wednesday 19 November 2008.

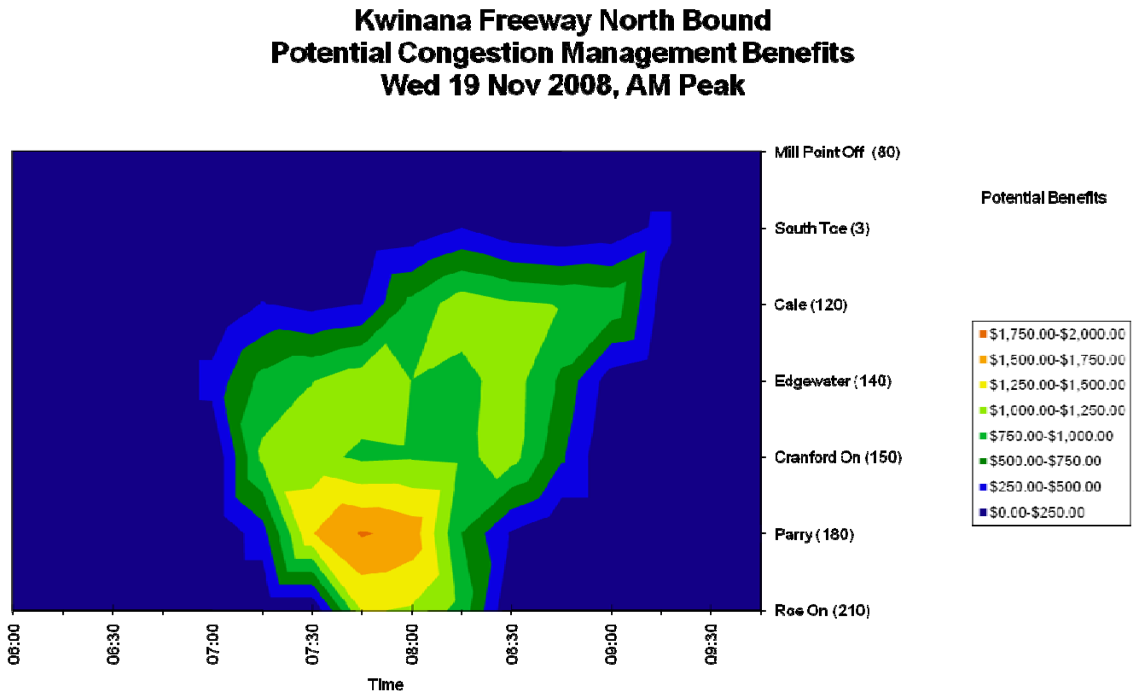

Figure 2: Potential benefits of applying advanced ITS to prevent productivity collapse based upon time and location.

The current Main Roads Data Cube is actually a prototype for the future, based upon the current freeway detailed traffic data set. Future directions include:

- Improved data screening and validation procedures;
- The consideration of other transport cost measures associated with sustainability such as noise, access, and equity;
- The consideration of transport cost measures associated with resilience; and
- The expansion of the cube to provide a network view including traffic signal data sets.

2.4 National Performance Indicators and Other Performance Reporting

Austroads Project NS1207 developed 'operational performance indicators suitable for the automated measurement of network performance'[2]. Based upon the Main Roads Data Cube, an application has been developed to provide reporting in accordance with the National Performance Indicator (NPI) methodology for Perth's freeways.

[2] R. Troutbeck, M. Su, J. Luk, Austroads Research Report, National Performance Indicators for Network Operations, AP-R305-07, Austroads, September 2007.

There are four NPI reports for freeways:

- Efficiency (Average Travel Speed);
- Efficiency (The percentage of freeway operating within levels of variation from the posted speed limit);
- Productivity (Percentage of network operating within different productivity bands); and
- Reliability (Percentage of network operating with differing degrees of travel speed fluctuations from day to day through the reporting period).

The reports consider working day data during the selected peak periods and aggregate the calculation outcome across the time period in time and space. For the Efficiency (Average Travel Speed) indicator, this results in a single number representing the average travel speed – see Figure 3. The outcome for the other indicators represents the percentage of the freeway performing within each performance band both in time and space – see Figures 4, 5 and 6.

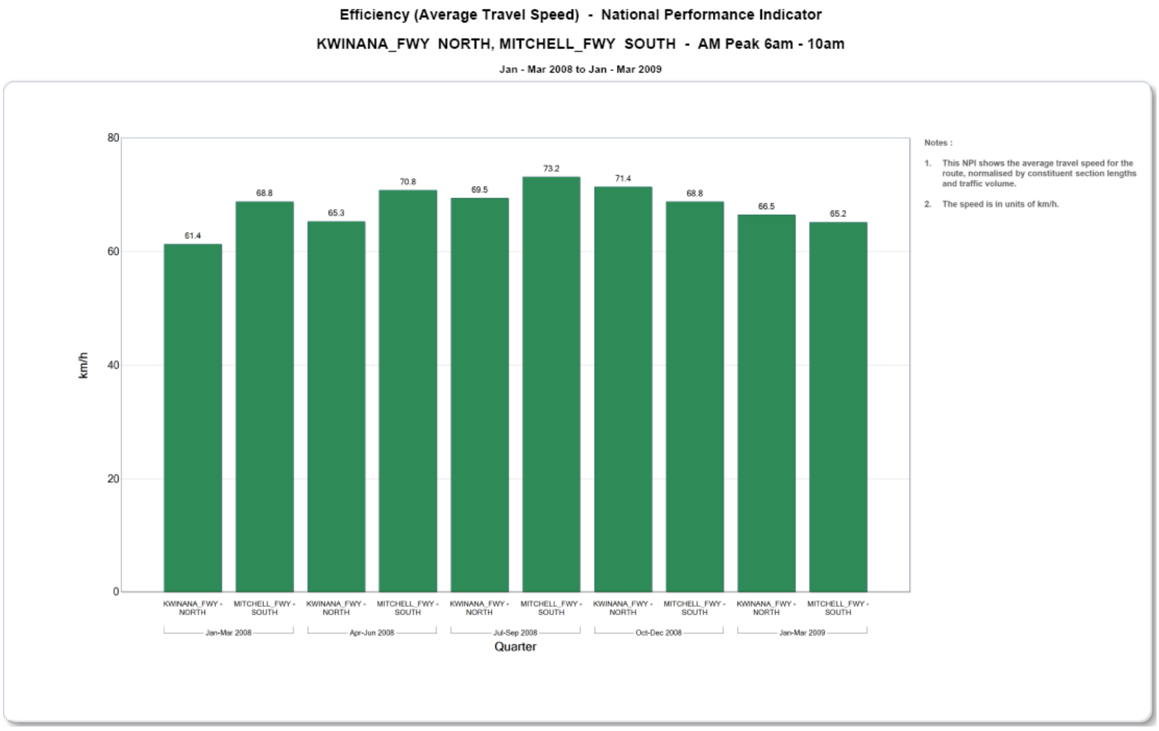

Figure 3: National Performance Indicator report comparing the Efficiency (Average Travel Speed) of Kwinana Freeway (north bound) and Mitchell Freeway (south bound) during the morning peak period between 6am and 10am.

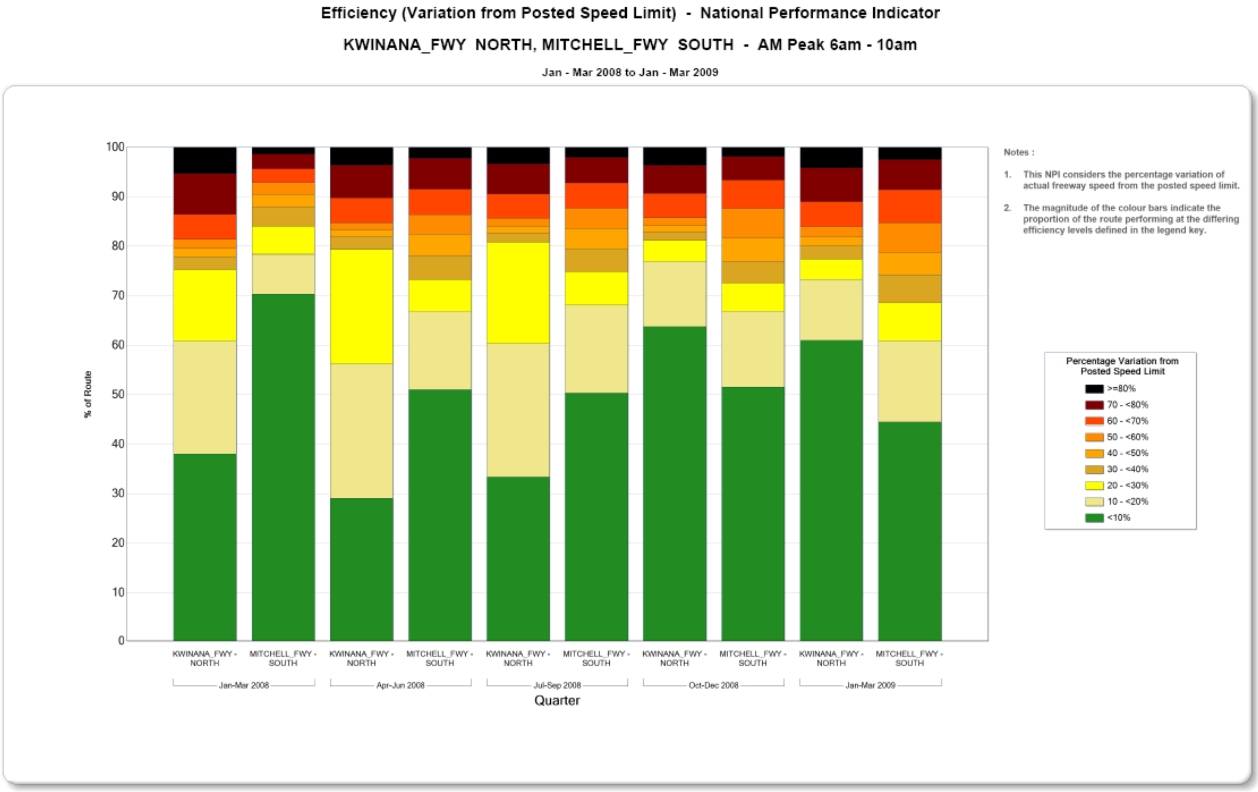

Figure 4: National Performance Indicator report comparing the Efficiency (Variation from Posted Speed Limit) of Kwinana Freeway (north bound) and Mitchell Freeway (south bound) during the morning peak period between 6am and 10am.

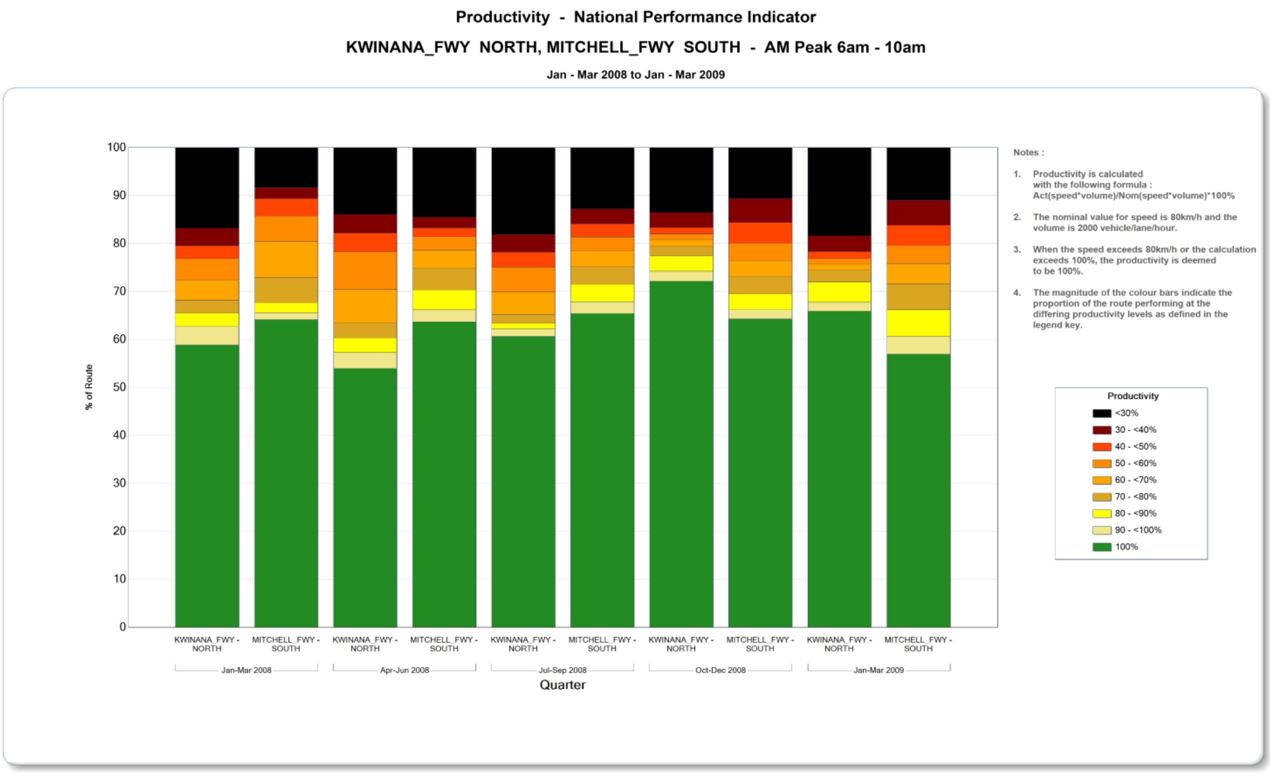

Figure 5: National Performance Indicator report comparing the Productivity of Kwinana Freeway (north bound) and Mitchell Freeway (south bound) during the morning peak period between 6am and 10am.

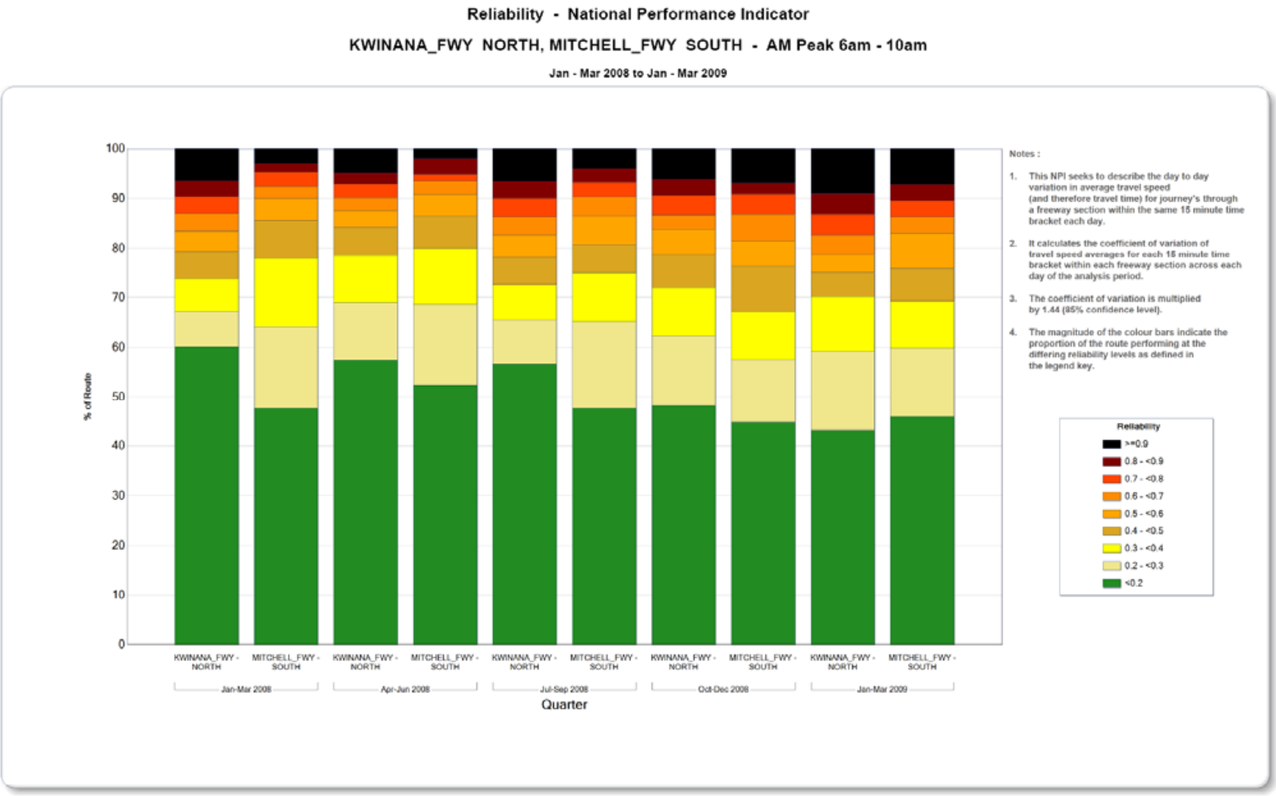

Figure 6: National Performance Indicator report comparing the Reliability of Kwinana Freeway (north bound) and Mitchell Freeway (south bound) during the morning peak period between 6am and 10am.

Main Roads is developing similar reports for the "direct" costs of travel and congestion associated with estimated travel time costs, reliability time costs, fuel consumption and vehicle emissions (e.g. greenhouse gas emissions). In addition, Main Roads is developing other methods for presenting the information, such as Graphical Information System (GIS) presentation of the road network, with colouring of the road network corresponding with the appropriate performance band.

3. ARTERIAL NETWORK TRAFFIC SIGNAL DATA

Main Roads presently uses the Sydney Coordinated Adaptive Traffic Signal (SCATS) system to manage the real time operations associated with all traffic signals in Western Australia.

While the loop detectors and Traffic Signal Controllers register every detector activation and deactivation, only summarised information is used by SCATS for signal phase optimisation and coordination. The summarised data is based upon "Strategic Approaches" which represent traffic lane groupings that provide the most important data for the signal phase optimisation and coordination. Therefore, the dataset available from the Strategic Approaches is not comprehensive and highly summarised, reducing the

quality of analysis that can be achieved. Despite the reduced outcome quality, the dataset that is available can be used for advanced analysis purposes such as the estimation of travel times and determination of traffic densities for the relevant traffic lanes[3].

Main Roads is seeking to develop the capability to extract this information from the SCATS system and apply an automated process that provides advanced analysis outputs for real time and historical network performance reporting. Investigation is proceeding to determine appropriate processes and assumptions in order to generate a relatively useful and accurate picture of network performance.

Upon system implementation, the level of accuracy is intended to be confirmed by comparing floating vehicle datasets with the system outputs. If a suitable level of accuracy is found, then the output will still form a basis for estimation of Sustainability Indicators associated with travel time and environmental emissions. Accordingly, it is a project objective to provide the capability for the reporting of indicators that are similar to the freeway, although weaker in accuracy and detail.

4. FLOATING VEHICLE DATA

Floating Vehicle Data (FVD) describes network performance data retrieved from vehicles travelling the road network. It may be acquired through fleet management systems, usually involving the Global Positioning System (GPS), mobile phone tracking systems, electronic tag tracking systems (e.g. toll operators) or vehicle recognition systems (e.g. Automatic Licence Plate Recognition and electro-magnetic vehicle signature measurement).

FVD has the potential to provide information about what is happening between traditional infrastructure based vehicle data systems (e.g. inductive loops), through locations without traditional vehicle data infrastructure and (in the case of the GPS fleet management systems) potentially with a high data frequency; however, there are issues associated with data ownership, reliability and actual data frequency. Firstly, while some data owners are pleased to pass their data to the road authority, initial investigation has found that many are not. Secondly, by normal measure, FVD has very high reliability, however, many of the systems utilise mobile phone communication pathways or systems, which can be prone to failure during important occasions such as major incidents and events, which is arguably when performance data is needed most. Finally, to reduce

[3] P. Bennett, J. Luk, B. Marsh, Real Time Estimation of Travel Time on Arterial Roads – The ARRB Travel Time Model, CAITR, December 2008.

costs, maximise battery life (e.g. mobile phone sampling) or to operate within available bandwidths, many FVD sets have relatively low sampling frequencies, reducing the ability to rapidly characterise network performance issues. While future advances are likely to address many of these issues, it is proposed that data source diversification provides the best solution.

MRWA presently has limited access to FVD. In the case of fleet management, few vehicles are equipped with this capability. In the case of mobile phone data, there remain questions in association with the data reliability plus there is a cost involved in acquiring the data. In the case of other vehicle tracking systems, infrastructure for this purpose (e.g. toll roads) does not presently exist. By contrast, MRWA is close to having significant VDS coverage of the freeway network and access to all traffic signal data. Accordingly, the current focus is upon using available FVD data, manual FVD survey's, to assist with the calibration of algorithms that estimate network performance based upon the VDS and Traffic Signal data sets.

A significant advantage provided by the MRWA approach is that the VDS and Traffic Signal data sets are already reliable and are becoming more reliable. They are already reliable because their communication pathway is not significantly prone to failure as it is commonly based upon an isolated network. Further reliability is emerging through the application of Unlimited Power Supply (UPS) systems at key locations (particularly Traffic Signals) and through the development of diverse communication pathways. For example optic fibre communication rings are presently being deployed through Foundation ITS projects and programs – see Figure 7.

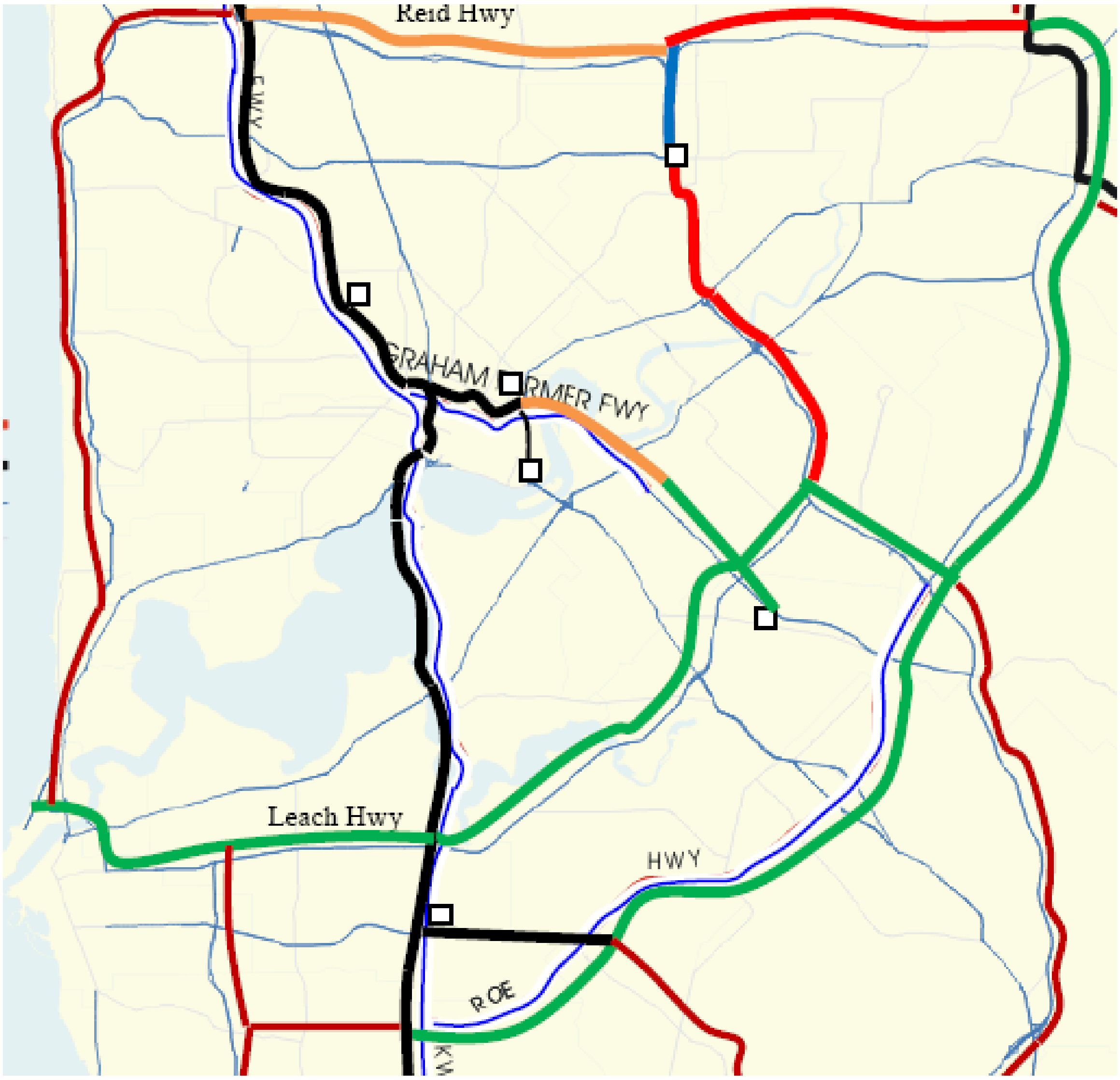

Figure 7: An excerpt from MRWA optic fibre planning process highlighting multiple optic fibre rings are being formed to provide diverse communication pathways, increasing the reliability of the communications system.

Supporting this approach is assessment of three key arterial road network roads of Reid Highway, Tonkin Highway and Leach Highway for accuracy of travel time estimation based upon the available Traffic Signal data. The algorithms were manually calibrated using FVD collected for this purpose. It was found that high levels of travel time estimation accuracy could be achieved through this process at route level with the correlation co-efficient and coefficient of determination exceeding 0.9[4]. The only deficiency associated with the trial exercise was the need to recalibrate the system over time to cope with amendments to Traffic Signal infrastructure, road infrastructure and operational regimes. To overcome this limitation and a process is being developed for

[4] P. Bennett, J. Luk, B. Marsh, Real Time Estimation of Travel Time on Arterial Roads – The ARRB Travel Time Model, CAITR, December 2008.

the automatic update of the system calibration, forming part of the automated system for extracting travel time information for the arterial road network alluded to in Section 3.

5. NETWORK VIEW OF PERFORMANCE

Section 3 notes the intention for arterial road data extraction based upon the Traffic Signals and SCATS system to be analysed to produce outputs similar to the freeway data. Section 4 refers to the application of available FVD to enable the automated calibration of systems used to estimate travel time, particularly based upon the Traffic Signal data. It is further noted that a similar process is proposed for the freeway data sets.

However, there are roads which exhibit characteristics of both freeway and arterial roads as they include grade separation at some intersections, sometimes long distances between intersections (e.g. proposed freeways) and retain traffic signals at some (if not all) intersections. Further, the true freeway network interacts with the arterial road network at interchanges, which involves a transition between freeway and Traffic Signal data sets.

To enable a single picture of network performance to be efficiently formed, it is essential that the alternative data sets be combined. Accordingly, MRWA is developing such a process.

Initially the process will involve generalisations and assumptions that are not always accurate at the micro level, however, provide a relatively accurate picture at the macro level. An example of a generalisation is associated with alternative pathways from a single traffic lane at a set of traffic signals; where arrows are painted on the road to define the pathway options (according to the Traffic Signal records in SCATS) traffic volumes will be initially allocated equally across those pathways. Clearly, this generalisation is at great risk of being inaccurate when a particular traffic signal set is considered at a selected time of the day. However, the fact that the arrows have been identified, compared to a circumstance where they have not, represents recognition that the pathway options are all important and so are each likely to receive significant traffic flows. It is a matter of probability as to which is the more significant flow at the localised scenario rather than a consistent trend. Accordingly, at the macro level, the generalisation is considered to provide a relatively accurate representation.

The system will enable the generalisations and assumptions to be adjusted for individual circumstances, which is important given the system will generate priorities for

improvement investigation (e.g. to consider operational improvement of the Traffic Signal coordination). Should the investigation reveal that the deficient performance at a location does not represent reality due to an assumption or generalisation being too inaccurate, then adjustment can be made to the specific location.

The final feature of the system is that it will involve a data cube structure for the historical analysis. This feature will enable prompt assessment of priorities and rapid reassessment as many system adjustments occur. While the cube will also have constraints, such as rules associated with the dimension settings are more difficult to adjust, the cube will enable faster processing and report building due to the advanced data organisation.

6. CONCLUSION

The Network Intelligence Project of MRWA is an exciting project that is developing capability in advanced data sets for Transportation and Traffic Engineering. Key features include sustainability performance indicators, automated reporting systems, detailed technical analysis, integration of diverse data sets, application of data cube technology and real time performance information publishing.

While the Network Intelligence Project is far from complete, significant results have already been achieved, particularly in the freeway Vehicle Detection Station area and the historical data analysis context. These results are positioning MRWA well in relation to achieving the benefits of ITS.

Further development stages include traffic signal data (through the SCATS), application of Floating Vehicle Data (to calibrate algorithms estimating network performance between VDS and traffic signals) and development of a unified “cube” that provides a network view of performance.